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A review on emission analysis in cement industries

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ABSTRACT

The cement subsector consumes approximately 12–15% of the total industrial energy use. Therefore, this subsector releases CO_2 emissions to the atmosphere as a result of burning fossil fuels to produce energy needed for the cement manufacturing process. The cement industry contributes about 7% of the total worldwide CO_2 emissions. This study complied a comprehensive literature in terms of Thesis (MS and PhD), peer reviewed journals papers, conference proceedings, books, reports, websites for emission generation and mitigation technique. Emission released associated with the burning of fuels have been presented in this paper. Different sources of emissions in a cement industry has been identified and presented in this study. Different techniques to reduce CO_2 emissions from the cement manufacturing industries are reviewed and presented in this paper. The major techniques are: capture and storage CO_2 emissions, reducing clinker/cement ratio by replacing clinker with different of additives and using alternative fuels instead of fossil fuels. Apart from these techniques, various energy savings measures in cement industries expected to reduce indirect emissions released to the atmosphere. Based on review results it was found that sizeable amount of emission can be mitigated using different techniques and energy savings measures.

Contents

1. Introduction

The cement industry is one of the major contributors for greenhouse gases (GHG) emissions, specifically CO_2 emission. This is due to the calcinations of raw materials for the production

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Nomenclature

a	fuel type
b	sector or source activity
CaO_{Cl}	calcium oxide (CaO) content of clinker produced
Cic	cost of applying CO_2 capture technology (c) on unit i (US$/year)
Cie	cost of applying efficiency improvement technology (e) on unit i (US$/year)
Cif	operating cost for a unit i with fuel f (US$/ton)
$Clinker_{content}$	percentage of clinker in the cement ($t_{clinker}/t_{cement}$)
Cr	cost of purchasing raw material r (US$/ton)
EF_{cl}	emission factor for the clinker produced (ton CO_2/ton clinker)
$Energy_{kiln}$	associated with the kiln technology (MJ/$t_{clinker}$)
$Fuel_{emis}$	CO_2 released from fuel burning (t_{CO_2}/MJ)
MgO_{Cl}	magnesium oxide (MgO) content of clinker produced
Pif	amount produced from unit i using fuel f (ton/year)
$Production_{cement}$/year	production of cement per year (t_{cement}/year)
Q_{cl}	quantity of clinker produced (ton).
$Raw-mat_{emis}$	refers to the CO_2 released from the raw materials and is then expressed in ($t_{CO_2}/t_{clinker}$)
Rif	retrofit cost for switching unit i to run with another fuel f (US$/year)
Rr	purchased amount of raw material r (ton/year)
Xif	binary variable representing switching or not.
Yie	binary variable representing applying efficiency improvement technology (e) or not.
Z	annualized capital and operating cost of the cement plant (US$/year)
Zic	binary variable representing applying CO_2 capture technology (c) or not.
44.0/56.1	stoichiometric ratio of CO_2/CaO stochiometric ration is 0.785
44.0/40.3	stoichiometric ratio of CO_2/MgO

of cement and burning fuels needed to maintain high temperatures in a Kiln. In recent times, one of the most important goals of the global environmental agenda is the reduction of emissions to protect the Earth's climate pattern. The increasing trend of atmospheric emissions is a driving factor to design and develop policies to overcome challenges facing by climate change.

Cement industry subsector require about 12% of total energy use in Malaysia [1] and 15% in Iran [2,3]. It is observed that coal, fuel oils and petroleum coke are the major sources of energy needed in a cement manufacturing process. Recently natural gas, and alternative fuels found to be used by many cement industries around the world [4]. Approximately seven percent of the total CO_2 is emitted by cement industries [5]. This percentage is rapidly increasing mainly because cement production is increasing at a faster rate than the speed at which emissions are presently reduced [6].

China is the major cement producer around the world and it produced 1388 million metric tons (MMT) of cement in 2008. This accounts for nearly half of the world's total cement production [7]. Indian cement industry is the second largest in the world with an installed capacity of 135 MMT per annum. It accounts for nearly 6% of the world production [8]. At present, the United States is the third major cement producer in the world next to China and India [4]. In 2002, the United States produced 89,000,000 metric tons of cement [9]. Fig. 1 shows worldwide cement production statistics [10].

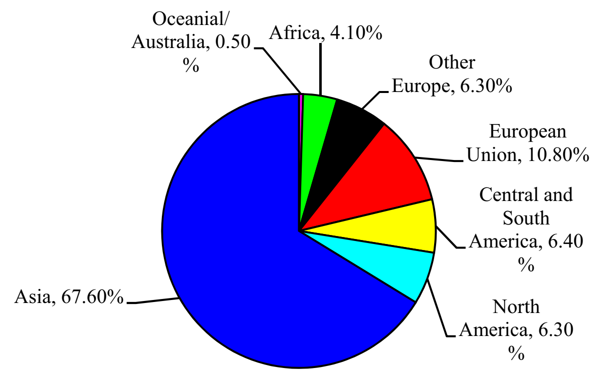

Fig. 1. Worldwide cement production in 2004 [10].

Table 1
Comparison of electrical and thermal SEC for few selected countries around the world [12].

Country	Electrical SEC (kWh/ton)	Thermal SEC (GJ/ton)
India	88	3.00
Spain	92	3.50
Germany	100	3.50
Japan	100	3.50
Korea	102	3.70
Brazil	110	3.70
Italy	112	3.80
China	118	4.00
Mexico	118	4.20
Canada	140	4.50
US	141	4.60
World best	65	2.72

2. Specific energy consumption

A plant or process with a lower SEC value corresponds to a similar plant or similar process that is more energy efficient. By comparing to SEC, the information developed can be used to assess the energy-efficiency potential of a plant. The SEC can also be used for evaluating and tracking a plant's progress in energy-efficiency improvements by eliminating the effects of a change in product mix [11]. Average specific thermal and electrical energy consumption is presented in Table 1 for few selected countries.

Table 2 shows specific thermal energy consumption for different types of clinker manufacturing process. It has been observed that pre-heating with different stages can reduce energy consumption significantly. Waste heat from different sources is used to pre-heat the clinker.

Table 2
Specific thermal energy consumption in a clinker manufacturing process [13].

Kiln process	Thermal energy consumption (GJ/ton clinker)
Wet process with internals	5.86–6.28
Long dry process with internals	4.60
1-Stage cyclone pre-heater	4.18
2-Stage cyclone pre-heater	3.77
4-Stage cyclone pre-heater	3.55
4-Stage cyclone pre-heater plus calciner	3.14
5-Stage pre-heater plus calciner plus high efficiency cooler	3.01
6-Stage pre-heater plus calciner plus high efficiency cooler	Less than 2.93

Table 3
Specific electrical energy consumption in dry and wet process [2].

Process sections	Electrical energy consumption (kWh/ton)	
	Dry	Wet
Raw material treatment and crushing	4	3
Mashing	44	10
Fans and coolers	23	25
Dust collector	6	8
Cement milling	45	45
Transportation	8	58
Total electricity required (kWh/ton)	130	149
Fuel burned in furnaces (lit/ton)	112.5	156

Table 3 shows specific electrical and thermal energy consumption for wet and dry process. It has been observed that dry process is more efficient compared to wet process. In a wet process extra energy is needed to remove moisture contained in wet slurry. Industries around the world are moving towards dry manufacturing process as they consume less energy than a wet process. Dry process consumes about 13% less energy (electrical) than a wet process. Dry process found to consume about 28% less fuel than a wet process.

Table 4 shows specific electrical and thermal energy consumption trend in Polish cement industries. As industries are implementing different energy savings measures, this consequently will reduce specific energy consumption.

3. Emissions from cement industry

About one third of the global carbon dioxide (CO_2) emissions released to the atmosphere are associated with the use of energy at various industrial sectors [14,15] reported that industry emitted about 2370 Tg CO_2. This accounts for about 43% of global CO_2 emissions. Deja et al. [5] reported that cement industries contribute for about 7% of the total global CO_2 emissions. It is estimated that about 0.9–1.0 tons of CO_2 are produced for a ton of clinker depending on the type of fuels used [5,14]. Hoenig et al. [10] reported that 0.65–0.92 kg of CO_2 is produced for per kg cement produced based on a cement plant with a modern technology and equipment. In a study by [5] reported that on an average 0.79 ton of CO_2 is emitted for per ton of cement. Fig. 2 shows the energy related CO_2 emissions for few selected countries around the world [10]. The concentrations of CO_2 in flue gases are relatively high in cement production. And they are in the range of 14–33% [16].

Emissions of CO_2 in a cement industry mainly come directly from combustion of fossil fuels and from calcinations of the limestone into calcium oxide. An indirect amount of CO_2 comes from the consumption of electricity that is generated by burning fossil fuels. Approximately half of CO_2 emissions are originated from the combustion of fuels and half of them are originated from the calcinations of the limestone [14,17–19]. The typical exhaust gas compositions from a cement process is shown in Table 5 [20].

Table 4
Specific energy consumption in Polish cement industry [5].

Year	Consumption of electric energy (kWh/ton)	Consumption of unit gross heat energy (GJ/ton)
2002	105	3.77
2003	105	3.48
2004	102	3.41
2005	101	3.46
2006	101	3.50
2007	95	3.64
2008	94	3.64

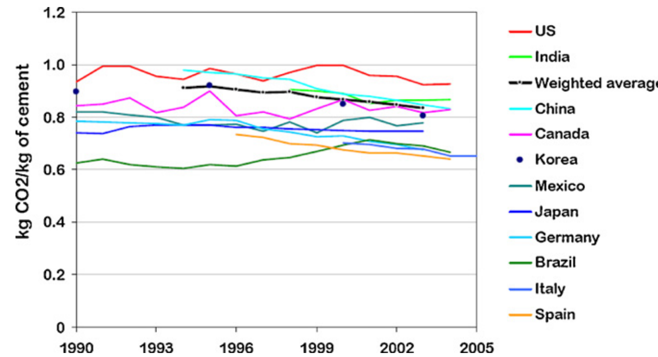

Fig. 2. Process and energy CO_2 emissions per ton of cement by country [10].

Table 5
Exhaust gases from cement process.

Component	Concentration
CO_2	14–33% (w/w)
NO_2	5–10 of NO_x
NO_x	<200–3000 mg/Nm^3
SO_2	<10-3500 mg/Nm^3
O_2	8–14% (v/v)

Global carbon dioxide emissions from cement manufacturing processes were about 829 million metric tons in 2000 as reported by [7]. Global CO_2 emissions trend is illustrated in Fig. 3 [21].

Total CO_2 emissions emitted from a cement plant can be considered as the sum of emissions released from the consumption of thermal energy and generation of electric energy required for the plant. Total CO_2 emissions can be estimated using Eq. (1) [14].

$$\text{Total}\quad CO_2\quad \text{emissions} = CO_2\quad \text{emission}_{\text{clinker use}} + CO_2\quad \text{emission}_{\text{electric energy use}} + CO_2\quad \text{emisions}_{\text{thermal energy use}} \tag{1}$$

3.1. Carbon dioxide emissions from calcination

Almost half of the CO_2 is produced from the calcination process where conversion of raw materials takes place [5]. The amount of CO_2 produced by the calcination can be expressed mathematically as [17]:

$$CaCO_3 \rightarrow CaO + CO_2 \tag{2}$$

About 64–67% of clinker composition is CaO and the remaining share consists of iron oxides and aluminum oxides. About 0.5 kg of

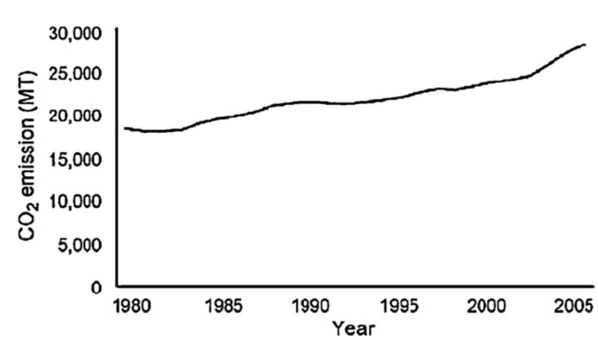

Fig. 3. Global CO_2 emissions from 1980 to 2005 [21].

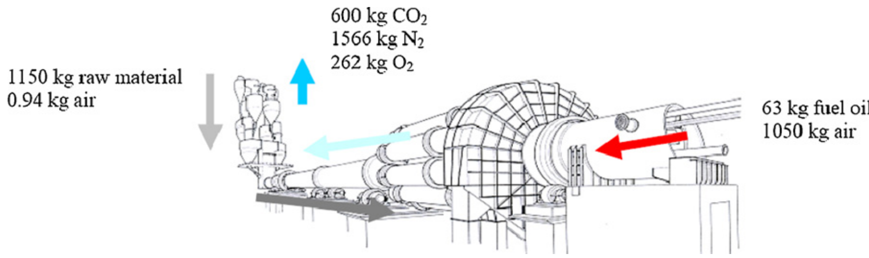

Fig. 4. Typical cement process mass balance [22].

CO_2 is produced for per kg clinker. Emissions of CO_2 are dependent on the clinker and cement ratio. This ratio varies normally from 0.5 to 0.95 [17]. The amount of CO_2 generated by the process varies on the basis of loss of the raw materials (limestone) during ignition. Fig. 4 shows the mass balance results of CO_2 emissions in a cement manufacturing process [22].

For CO_2 emissions from calcinations process based on clinker production data, the following equation can be used [23].

$$\text{Emissions (clinker production) } CO_2 = EF_{cl} \times Q_{cl} \tag{3}$$

The above equation assumes that all of the CaO and MgO in the clinker are produced from a carbonate source ($CaCO_3$, $MgCO_3$ in limestone). The emission factor (EF) is dependent on the CaO and MgO contents of the clinker. EF is also dependent on the stoichiometric compositions of the reaction. The EF can be expressed as [23]:

$$EF''_{cl''} = \frac{44.0}{56.1} \times \text{CaO} \left(\frac{44.0}{40.3} \times \text{MgO}\right) \tag{4}$$

3.2. The cement manufacturing process and CO_2 emissions

Limestone is a major raw material used in the production of cement. It is burnt at about 1450 °C to make clinker and is blended with additives. The finished product is then finely grounded to produce different types of cement [14]. Emissions are produced mainly by de-carbonation of limestone and the use of carbon based fuels for heating. Average CO_2 emissions associated with grinding processes are in the order of 0.1 ton of CO_2 per ton of cement and are mostly associated with electricity production [24]. Fig. 5 describes schematically the cement production process and associated CO_2 emissions at different sections of a cement manufacturing process [24].

3.3. Carbon dioxide emissions from fuel use

A fuel is burned to produce heat which in turn is used for producing clinker. A pyroprocess removes water from the raw meal, calcines the limestone at temperatures between 900 and 1000 °C. The amount of carbon dioxide emitted during this process is influenced by the type of fuel used (i.e. coal, fuel oil, natural gas, petroleum coke and alternative fuels). The total CO_2 emission during the cement production process depends mainly on type of production process, fuel used, and clinker/cement ratio [17]. Table 6 shows the global carbon emission from cement production.

Amount of CO_2 emissions produced by the cement industry can be expressed mathematically by Eq. (5) [17].

$$\frac{t_{CO_2}}{\text{year}[(\text{Fuelemis} \cdot \text{Energykiln}\ \ (\text{raw-matemis}) \times C_{\text{Linker content}}]} \quad \frac{\text{production cement}}{\text{year}} \tag{5}$$

Carbon dioxide emissions from stationary combustion processes can be expressed by the general equation [23].

$$\text{emission (stationary combustion) } CO_2 = \text{EFab} \times \text{xEFab} \tag{6}$$

Carbon dioxide emissions from whole process of clinker production can be expressed as:

$$\text{“Emission } CO_2\text{”} = \text{Emission (clinker production)}$$
$$\text{“}CO_2\text{” (emission (stationary combustion) “}CO_2\text{”} \tag{7}$$

4. Reduction of emissions from cement industry

The cement industry is one of the largest sectors that contribute emissions of CO_2 to atmosphere. This sector accounts for about 1.8 Gt of CO_2 emission annually [25]. At the moment, CO_2

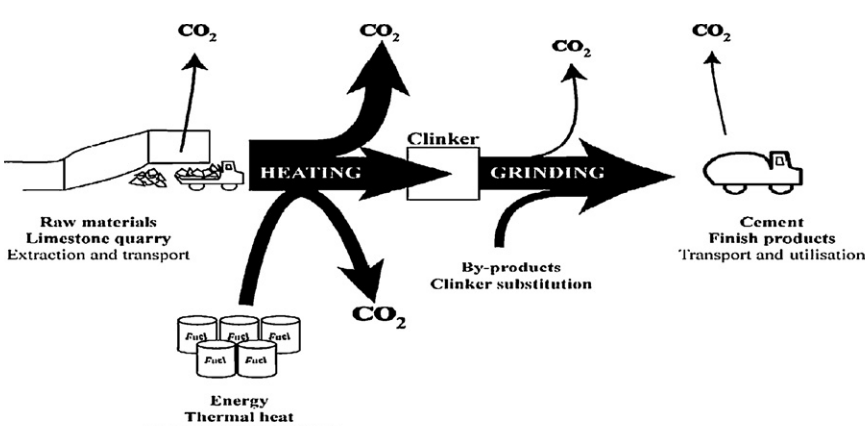

Fig. 5. Simplified cement fabrication process, with a specific interest in the CO_2 emissions [24].

Table 6
Global carbon emissions from cement production [17].

Country	Cement production (Tg)	Clinker/cement ratio (%)	Primary intensity (MJ/kg)	Primary energy (PJ)	Process carbon (Tg CO_2)	Carbon emissions (Tg CO_2)	Total (Tg CO_2)
China	423	83	5	2117	175	197	372
Europe	182		4.1	749	73	56	129
OECD Pacific	151		3.5	533	65	41	105
Other ASIA	124		4.9	613	56	179	105
Middle East	111		5.1	563	51	44	95
North America	88		5.4	480	39	40	78
EE/FSU	101		5.5	558	42	38	80
Latin America	97		4.7	462	42	30	71
India	62	89	5	309	28	30	60
Africa	41		4.9	201	18	15	33
Total	1381		4.8	6585	587	830	1126

reduction is the most important environmental target worldwide in order to reduce the atmospheric concentration of greenhouse gases. Followings are the few selected techniques that can be used to reduce CO_2 emissions from the cement manufacturing process [20,22,23,26–28]:

- Use of waste heat as an alternative source of energy;
- Implementation of CO_2 capture and storage technologies;
- Sequestering CO_2 by enhancing biological absorption capacity in forests and soils;
- Use of blended cement by reducing clinker/cement ratio;
- Increasing the use of renewable energy sources or nuclear energy;
- The raw mixture can be prepared with non-carbonated calcium;
- Use of alternative raw materials that contains carbonates (fly ash, slag, gypsum, anhydrite and fluorite).

Indirect CO_2 emission reductions can be achieved by reducing energy consumption in cement manufacturing. These can be done by applying energy savings measures for machineries used in cement manufacturing. Table 7 shows CO_2 reductions associated with different energy savings technologies.

There are other techniques to reduce CO_2 emission and energy consumption from cement industry. These can be achieved by introducing energy efficiency technologies and measures in cement industry as shown in Table 8.

4.1. Capture and storage technologies

In a carbon capture technique, a stream of concentrated CO_2 is transported and sequestered underground or in the deep Ocean. Carbon dioxide capture and storage (CCS) may become an emerging approach for CO_2 abatement using this technique, carbon dioxide could be captured and stored away for a very long period of time. Fig. 6 shows process of cement plant without CO_2 capture [20,31].

Newell and Anderson [16] reported that the application CCS technologies in cement production may reduce carbon emissions of CO_2 by 65–70%. In a cement manufacturing process, CO_2 is produced during the conversion of $CaCO_3$ to CaO and the combustion of a fuel to provide heat for the process [32]. Different methods for the capture of CO_2 at the point of combustion have been researched and developed [26]. The techniques include: chemical stripping, membrane system, cryogenic separation and physical absorption [22]. The implementation cost of each of these possibilities is highly uncertain; costs are directly related to technical performance, economic growth and fuel type [26]. The other possibilities for the capture process in cement industry include; post-combustion capture, oxy-fuel combustion capture and pre-combustion capture [10,22,31]. Fig. 7 presents an idea for CO_2 capture system.

Table 7
Technologies for efficiency improvements [22,26].

Technology	CO_2 emission reduction (%)
High efficiency motors and drives	4.0
Adjustable speed drives	5.5
High efficiency classifiers	8.1
Efficient grinding technologies	10.5
Conversion from wet to dry process	50.0

4.1.1. Post-combustion capture

Post-combustion capture of CO_2 from flue gases is produced by the combustion of fossil fuels and biomass in air. Instead of being discharged directly to the atmosphere, the flue gas is passed through equipment which separates most of the CO_2. In most cases, CO_2 is captured from a flue gas at low pressure and low CO_2 content. Generally, the efficiency of post-combustion abatement technologies increases with CO_2 concentration in the exhaust gas [10]. The CO_2 is fed into a storage reservoir and the remaining flue gas is discharged to the atmosphere. A chemical sorbent process is normally used for CO_2 separation [31,34].

4.1.2. Oxy-fuel combustion capture

In oxy-fuel combustion, almost pure oxygen is used for combustion instead of air. Therefore, a flue gas mostly contains CO_2 and H_2O [31]. If fuel is burnt in pure oxygen, the flame temperature is excessively high. However, CO_2 or H_2O-rich flue gas can be recycled to the combustor to reduce the excessive heat [10]. Oxygen is usually produced by a low temperature (cryogenic) air separation and novel methods to supply oxygen to the fuel, such as membranes and chemical looping cycles [31,34]. Fig. 8 illustrates the oxy-fuel process with a re-circulating flue gas.

4.1.3. Pre-combustion capture

Pre-combustion capture, a fuel is reacted with oxygen or air/steam to produce a 'synthesis gas that contains carbon monoxide and hydrogen. The carbon monoxide is then reacted with steam in a catalytic reactor to produce CO_2 and more hydrogen. Carbon dioxide is then separated, usually by a physical or chemical absorption process. The resulting fuel rich in hydrogen can be used in boilers, furnaces, gas turbines, engines and fuel cells [31,34]. Currently there is no pre-combustion technology used in a cement plant because they are designed for smaller volumes compared to the requirements of cement kilns [10]. Therefore, to apply pre-combustion technology in cement productions, the clinker burning process need to be modified.

In a cement industry, a separate hydrogen plant with carbon dioxide capture technology need to be built. Waste heat from the cement plant could provide some energy for reforming and shift reaction in the hydrogen production process. Even though the hydrogen production from natural gas, light hydrocarbons and coal

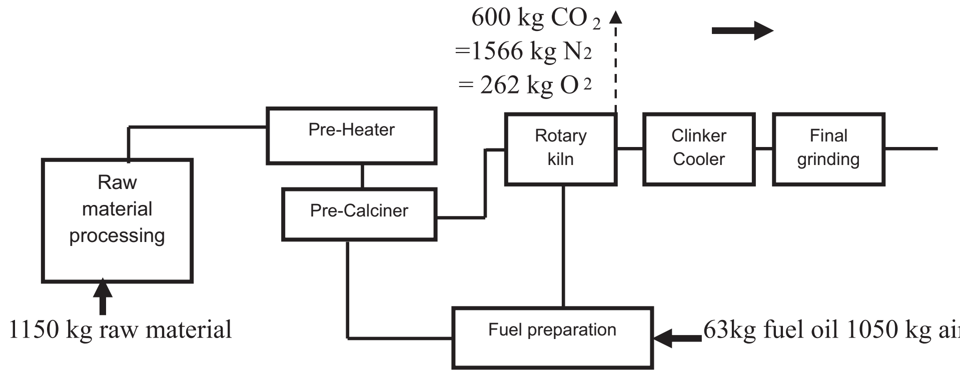

Fig. 6. Schematic of process flow of cement plant without CO_2 capture [20].

is a well-known technology, the subsequent capture and storage of CO_2 has not yet been applied [10].

A preliminary calculation suggests that the applications of CCS technologies in cement production could cut down carbon emissions by as much as 65 70%. If feasible, avoided capture and storage costs would likely be US$ 180/tC to US$ 915/tC [16]. The costs of a plant with and without capture technologies are summarized in Table 9 [25].

Table 10 shows the results of the cost CO_2 reduction associated with different percentage of CO_2 reductions.

Fig. 9 shows the global CO_2 emissions from cement industry with CCS capture and without capture.

Table 8
Summary of energy savings in clinker production, raw materials preparation and finish grinding [28–30].

Energy savings measures	Emission reduction ($kgCO_2$/ton)
Improved refractoriness for clinker making in all kilns	10.3–15.5
Energy management and process control systems for clinker making in all kilns	21
Adjustable speed drive for kiln fan for clinker making in all kilns	3.97
Installation or upgrading of a pre-heater to a pre-heater/pre-calciner Kiln for clinker making in rotary kilns	45.69
Conversion of long dry kilns to pre-heater/pre-calciner kilns for clinker making in rotary kilns	169.07
Dry process upgrade to multi-stage pre-heater kiln for clinker making in rotary kilns	141.44
Increasing number of pre-heater stages in rotary kilns	8.44
Conversion to reciprocating grate cooler for clinker making in rotary kilns	43.13
Kiln combustion system improvements for clinker making in rotary kilns	40.68
Indirect firing for clinker making in rotary kilns	0.39–0.57
Optimize heat recovery/upgrade clinker cooler for clinker making in rotary kilns	15.38
Low temperature heat recovery for power generation for clinker making in rotary kilns	19.18
Seal replacement for clinker making in rotary kilns	0.3
High temperature heat recovery for power generation for clinker making in rotary kilns	18.03
Efficient kiln drives for clinker making in rotary kilns	0.745
Replacing vertical shaft kilns with new suspension pre-heater/pre-calciner kilns for clinker making in vertical shaft kilns	62
Process control and management in grinding mills for finish grinding	2.63
Improved grinding media	3.34
High pressure (hydraulic) roller press for finish grinding	13.63
High efficiency classifiers for finish grinding	4.08
Efficient transport systems for raw materials preparation in dry process	2.61
Raw meal blending systems in dry process	1.37
Raw meal process control for vertical mills in dry process	0.94
High-efficiency classifiers in dry process	4.03
Slurry blending and homogenizing in wet process	0.15
Wash mills with closed circuit classifier in wet process	2.3
Roller mills for fuel preparation	0.25

Table 9
Summary of cement plant costs with and without CO_2 capture.

Descriptions	Unit	Base case (no capture)	Post combustion capture	Oxy-combustion
Capital cost	US$M	350	742	435
Operation cost				
Fuel cost	US$M/year	8.9	28.6	9.2
Electrical energy cost	US$M/year	5.3	-1.5	11.6
Other variable operating cost	US$M/year	8	14	9
Fixed operating cost	US$M/year	25	47	30
Capital charges	US$M/year	39	84	49
Total cost	US$M/year	87	172	109
Cement production cost	US$/ton	87	172	109
CO_2 abatement costs				
Cost per ton of cement product	US$/ton		85	21
Cost per ton of CO_2 captured	US$/ton		79	46
Cost per ton of CO_2 emission avoided	US$/ton		143	53

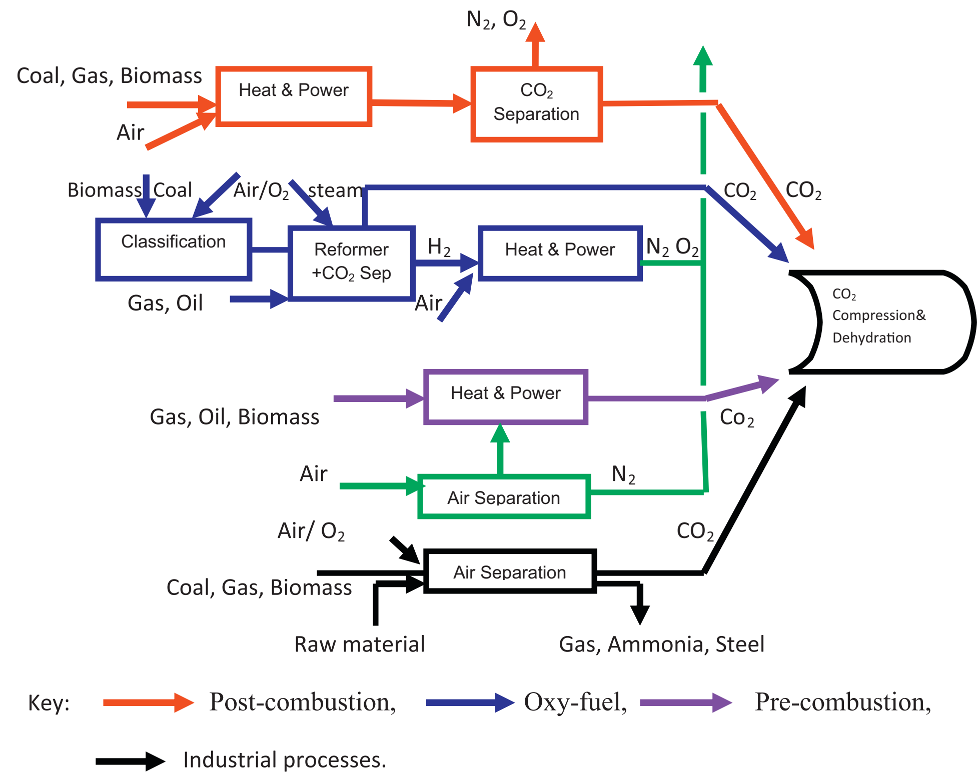

Fig. 7. CO_2 capture systems process [31,33].

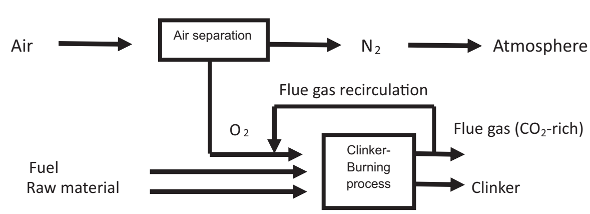

Fig. 8. Oxy-fuel technology with flue gas recirculation [10].

4.2. Reduction of clinker/cement ratio

A sizeable amount of CO_2 is emitted during the clinker production as it is an energy intensive process [20]. Reducing the amount of clinker in blended cement can be considered as one of the most effective ways to reduce CO_2 emissions. It was found that blending cement with the additives to replace clinker has the most remarkable contribution to the reduction of CO_2 emissions. In blended cement, the clinker/cement ratio is reduced by substituting a part of clinker with additives such as fly ash. An addition of about 10% fly ash to the cement would reduce annual CO_2 emissions substantially [23]. Cement and concrete quality can be improved with the addition of fly ash as well. In addition, limestone, blast furnace slag, natural pozzolans, silica fume and volcanic ash may also be used [24,35,36] as additives. It was reported that the granulated blast furnace slag is one of the widely used additives [37]. These industry based by-products are mixed with the ground clinker to give a blended cement product. The global potential for CO_2 emission reductions through the blended cement is estimated to be at least 5% of total CO_2 emissions from cement making. However it may be as high as 20% as reported by [20]. Fig. 10 presents the evolution of mineral additions in a cement manufacturing process. It shows that the percentage has remained roughly constant at about 20% over the last 30 years, but its nature has changed, with a diminution of blast furnace slags (BFS) and an increase in limestone addition [24].

4.3. Use of alternative fuels to reduce CO_2 emissions

Carbon dioxide emissions can be reduced by burning waste or biomass as alternative fuels. Cement kilns are well suited for the waste combustion because of their high process temperature [12].

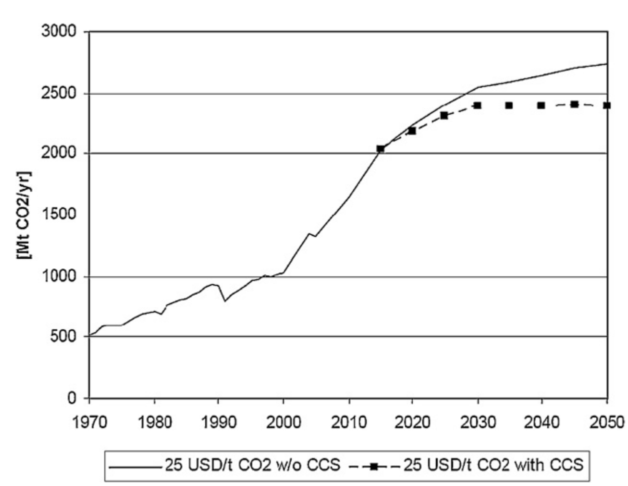

Fig. 9. Direct CO_2 emissions from cement production (1970–2050) [12].

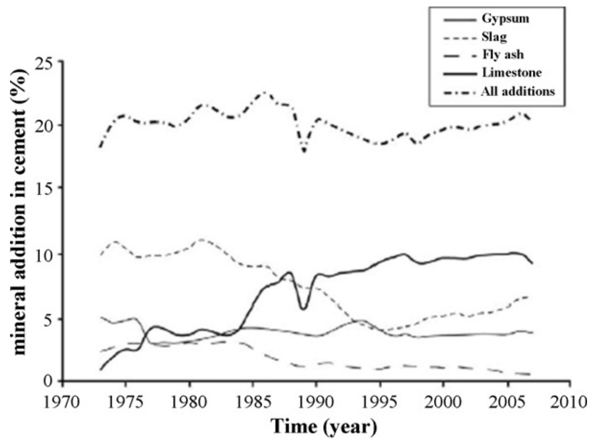

Fig. 10. Evolution of clinker substitution from 1973 to 2007 [24].

Alternative fuels used in the cement industry can be divided into three basic groups [38–40]:

- Gas (landfill gas, pyrolytic gas, biogas),
- Liquid (used oils, solvents),
- Solid (tires, wood waste, plastics).

Used chemicals, animal meal/fat, rubber, impregnated saw dust, sewage/industrial sludge, paper sludge and other types of waste can also be co-combusted in cement kilns in large quantities [12,41]. Substitutions of alternative fuels depend on the type of alternative fuel used. Fuel substitutions can be from 80% to 100% [42]. Belgium, France, Germany, the Netherlands and Switzerland have reached average substitution rates from 35% to more than 70% of the total energy used [12]. In the US, it is common for cement plants to derive 20–70% of their energy needs from alternative fuels [43]. The substitution rate in Europe is approximately 17% [41]. Few individual plants have even achieved 100% substitution rates using appropriate waste materials. However, very high substitution rates can only be accomplished if a tailored pre-treatment and surveillance system is in place [12]. The benefits of using alternative fuels in cement industry include [42,44,45]:

1. Reduction of CO_2 emissions as shown in Fig. 11;
2. Cost reduction of clinker production due to using inexpensive fuel;
3. Preservation of resources lower use of fossil nonrenewable fuel;
4. Reasonable secondary use of material;
5. Residue free combustion due to not existing ash, soil and sewage;
6. No significant change of emissions;
7. Hazardous substances will be destroyed due to the process—high temperature level, long gas residue time, alcalic combustion material, counter flow principle and oxidizing atmosphere;
8. High thermal efficiency;
9. Fulfillment of substantial dump disposal;
10. High yielding ecological balance.

Table 10
Result for different CO_2 reduction target [26].

CO_2 reduction (%)	Cost (million US$/year)	Increase in cost (%)
0	25	0
1	25.60	2.4
5	25.72	2.9
10	26.80	7.3
20	29.35	17.4
30	33.31	33.2
50	38.85	55.4

4.4. Pyroprocessing improvement

The greatest opportunities to reduce energy consumption and lowering emissions associated with cement manufacturing process will be obtained with improvements in pyroprocessing. Improvements can be made on the energy management, upgrading existing equipment, adopting new pyroprocessing technologies and R&D to develop completely new concepts for the cement manufacturing processes. Raw material drying at the raw mills; waste heat recovery from kilns exit gases using steam generator; and Kiln shell heat loss reductions can be considered for the pyroprocessing improvements. The typical pyroprocessing system is presented in Fig. 12 [46].

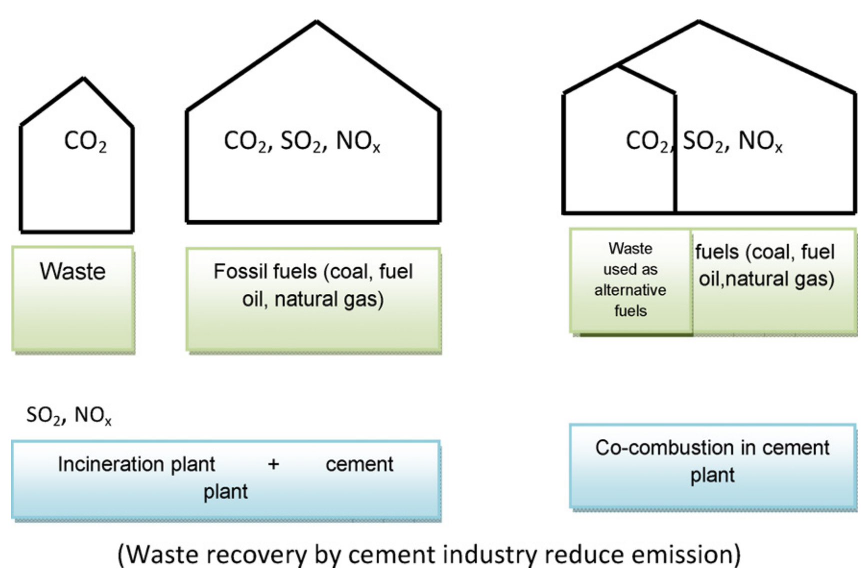

Fig. 11. Benefits of co-combustion of alternative fuels in a cement industry [43].

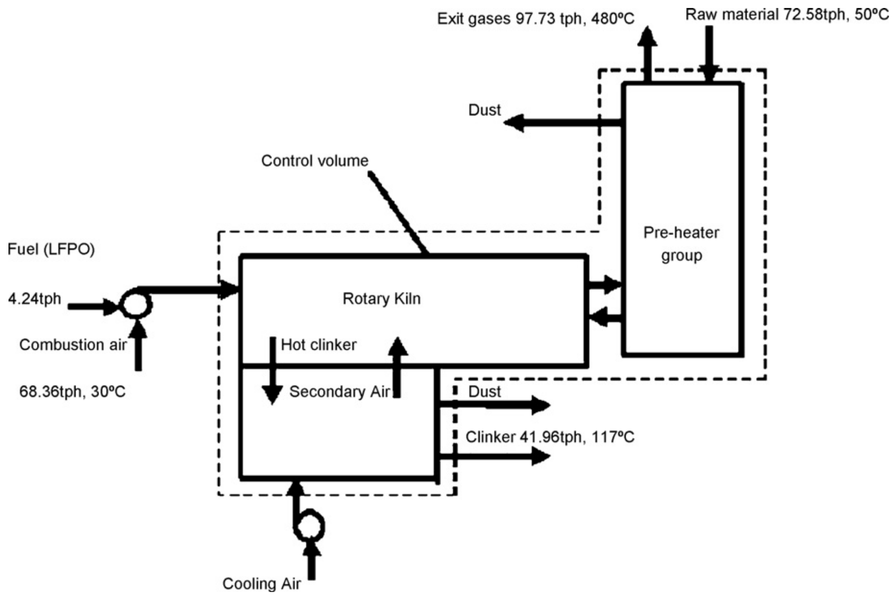

Fig. 12. Flow diagram of pyroprocessing system [46].

4.5. Optimized model

An optimization model an objective function for the cement industry is reported in this study. The objective of the model is to find the best strategy or mix of strategies to reduce CO_2 up to a certain target with minimum overall cost for cement production while meeting the demand. The model can be expressed as:

$$Z \quad (\$/\text{year}) = \sum_r CrRr + \sum\sum_{\text{If}} \text{Cif Pif} + \sum\sum_{\text{If}} \text{Pif} \times \text{if} + \sum\sum_{\text{Ie}} \text{Cie Yie} + \sum\sum_{\text{Ic}} \text{Cic Zic} \tag{8}$$

The first term in the objective function represents the cost associated with purchasing the raw material. The second term takes into account the operating cost for different units. The cost of switching to less carbon content fuel is shown in the third term. The fourth term represents the cost associated with applying efficiency improvement technologies. The remaining term adds the cost that result from applying CO_2 capture technology. A binary variable is defined for each CO_2 mitigation option [26].

5. Conclusions

It has been found that cement manufacturing is an energy intensive industry consuming about 12–5% of total industrial energy use. Therefore, sizeable amounts of emissions are released to the atmosphere as a result of burning fossil fuels to supply energy requirements of these industries. Emissions are produced from the calcinations process as well. For these reasons, special attention is needed on the clinker production to reduce CO_2 emissions. It was identified that there are several effective measures those can be applied in cement industries to achieve emissions reductions target. One of the most cost effective ways is to capture CO_2 from the flue gases and store it away into the soil or ocean. This can reduce carbon emissions by as much as 65–70%. By reducing clinker/cement ratio with the addition of various additives, CO_2 emissions can be reduced substantially. However, it was found that the substituting fossil fuels with alternative fuels may play a major role in the reduction of carbon dioxide emissions. These measures will reduce environmental impacts along with the overall of quality cement production.

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